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Integrating CAD, 3D-printing technology and oral communication to enhance students' physics understanding and disciplinary literacy

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Abstract

How do engineering physics students come to understand and share their physics learnings as a result of careful integration of oral communication with engineering skills like computer aided design and 3D-printing technology? Based in a sociocognitive theory of situated communication pedagogy, the action research conducted in this study set out to answer this research question in an introductory first-year course in engineering physics. A re-design intervention was planned, overseen, and evaluated by a teaching team comprising three physicists and a communication specialist. The findings—supported by student surveys, reflective field notes from the teachers' observations, and a focus group interview with students—strongly indicate that the students' structured oral engagement with disciplinary content confer learning benefits and promote the development of disciplinary (physics) literacy.

Keywords: communicating-to-learn, poster presentation, oral presentation, CAD, 3D-printing

(Some figures may appear in colour only in the online journal)

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1. Introduction

Meaningful academic (and later on professional-community) participation presupposes a learning environment that fosters disciplinary (physics) literacy and the emergence of a discursively driven disciplinary identity. According to Allie *et al*, being a competent member of a disciplinary community means being fluent ‘in the particular ways of reading, writing, speaking, using symbolic systems including mathematics and modelling, using tools, behaving, interacting ... that are considered appropriate by that discourse community’ [1, p 363]. In this regard, education in physics, and the development of disciplinary literacy in physics, is no exception, as evidenced by a recent report from the joint task force on undergraduate physics programs (J-TUPP, a collaboration between the American Physical Society and the American association of physics teachers with support from the National Science Foundation) where the development of scientific and technical skills, communication skills, and professional and workplace skills are held in as high regard as physics-specific knowledge [2].

While disciplinary physics skills and skills development are highly valued by stakeholders, engineering physics students are sometimes harder to convince, especially when they experience a lack of justification for engineering physics skills education and/or where the alignment and integration of skills with physics-specific knowledge is poor. To this end, and as acknowledged by the J-TUPP report, significantly more can be done by curriculum designers and by engineering physics educators in the classroom to emphasize the necessary interdependence between disciplinary skills and ‘core’ physics knowledge.

This paper presents observations, findings and pedagogical reflections from action research conducted in a first-year introductory engineering physics course which incorporated skills development (software, simulation, design, and communication) and physics-specific knowledge. The course in question was plagued by two primary problems:

- (a) Students’ perception of not engaging in physics and an apparent disconnect between physics and the communication of physics.
- (b) Teachers’ frustration with the students’ superficial understanding of physics, and the students’ failure to fully recognize the power and centrality of communication in doing physics.

These problems were identified, observed, and reflected upon by a teaching team comprising three physicists and a communication scholar. Jointly, the teachers decided to plan, implement and evaluate an educational intervention based in ideas of communicating-to-learn physics. With the hope of achieving several critical changes in the learning environment and the learning behavior of the students involved, this study follows a well-established tradition of action research in physics education [3–5].

The structure of the paper broadly reflects the fundamental stages of action research in education: observing a problem in a learning context, planning, theorizing and implementing action, and reflecting on the results of the action.

2. The target course; identifying a need for action

‘Tools in engineering physics’ is a mandatory first-year course (worth 10.5 credits according to the European credit transfer and accumulation system and spread across one and a half semester) in the five-year engineering physics program at Chalmers University of Technology. The course is a five-module introductory course, the purpose of which is to provide students with fundamental skills necessary for study and future engineering physics work. This includes

experimental methodology and the principles of physical modeling and simulation, including the use of computing equipment and simulation software. Module five of the course—a project module—focuses on computer-aided design (CAD) and 3D-printing and is used also for the purpose of introducing students to oral communication.

Until 2018, students in the course were required to design and 3D-print a small plastic object of their choice—the nature of the task was deliberately open. Before selecting a basic design, the students attended an introductory class on modelling in CAD. They were allowed to develop their model in the CAD-lab, with some limited supervision, during five two-hour sessions. The models were 3D-printed by the students themselves (printing was capped at four hours, introducing a size restriction on the object) under the supervision of a CAD-teacher. The oral communication component emphasized *generic* academic oral communication (rather than *disciplinary* oral communication reflective of an engineering physics environment) and students gave two monologic presentations in front of the class using Power Point. In the first presentation students introduced each other to features and functions of the CAD-program; the second presentation focused on the process of designing and printing and encouraged students to speak about aspects of the physics of the object.

Students expressed frustration with the open nature of the design task—and the fact that design appeared to be emphasized at the expense of physics. In the eyes of the teachers, students frequently came across as uncertain when explaining the physics of the object they had designed—if physics featured in the presentation at all. Additionally, students expressed low motivation for the oral communication activity and lamented the lack of alignment between their learning physics and what some referred to as the ‘giving a speech’ component of the course.

The students’ critique and the teachers’ experience of a sub-optimal learning environment prompted a critical review of the design of the course, resulting in an effort to re-design the module in question.

3. Theoretical framework: re-design inspired by a situated communication pedagogy

Deliberations among the teachers led to the conclusion that the re-design (or action strategy, cf. [6]) should be centered around the communication component—i.e. to let a new oral communication activity in the course serve as a vehicle for enhancing the physics learning environment. This reasoning was inspired by multiple reports of communication components being successfully integrated with science and engineering elsewhere, and the widely held belief that this is beneficial for students’ developing situated communication skills [7–9] and for furthering content learning, either directly or indirectly through the application of cognitive and metacognitive learning activities [7, 10–12]. It is notable, however, that significantly less research has been conducted on the integration of physics and communication [10]. The benefits of integrating communication and content have been particularly evident in cases where the communication activities mirror those engaged in by academics and professionals within the discipline [7, 11, 12]. Thus, by exploiting a symbiotic relationship between communication and content teaching—and given the appropriate conditions—students seem able to appropriate disciplinary communication while also communicating to learn the disciplinary content.

Further inspiration for the intervention was sought from Dannels’ [7, p 147] sociocognitive theory of communication and her thesis that integrated oral communication should involve ‘a situated communication pedagogy’ resting on four fundamental principles:

- (a) ‘oral genres are sites for disciplinary learning’: to this end, communication should help the students to socially construct what it means to be an engineering physicist;
- (b) ‘oral argument is a situated practice’: through communication, the students should learn what counts as valid knowledge and argumentation in engineering physics;
- (c) ‘communication competence is locally negotiated’: by actively engaging in disciplinary communication, the students should learn what counts as communicative competence in physics; and
- (d) ‘learning to communicate is a context driven activity’: communication is always viewed as contextual, even within a single discipline such as engineering physics.

The foundation of Dannels’ theorizing in this regard is echoed by later research with a specific focus on the development of disciplinary literacy in physics undergraduate education. Airey and Linder [13, p 28] (see also later work such as [14, 15]) adopt the term ‘disciplinary discourse’ to refer to ‘the complex of representations, tools and activities of a discipline’. They argue that ‘[e.g. physics] students need to become fluent in a critical constellation of the different semiotic resources—or modes of disciplinary discourse as we depict them—before they can appropriately holistically experience the disciplinary way of knowing that these resources/modes potentially give access to’. This understanding of disciplinary discourse is readily compatible with Dannels’ understanding of situated communication pedagogy; both these theoretical conceptions (disciplinary discourse and situated communication pedagogy) were useful in informing the present study.

Ultimately, the objective of the action research strategies came to center around the integration of structured oral communication with hands-on engineering physics components in the course, all of which is integral to the disciplinary discourse and which provide the students opportunities to co-construct ‘sites of disciplinary knowledge’ so that, at a fundamental level, ‘the norms, epistemologies, and values’ of the physics discipline—i.e. effectively a disciplinary identity—may be appropriated by the students [16, p 265]. Thus, it was hoped that oral communication could be viewed as an ‘enabler’ of emergent disciplinary literacy, and that it might enthuse students to engage with the physics at a deeper level. The research question that this study set out to address was formulated thus:

How do first-year engineering physics students come to understand and share their physics learnings (content, level of disciplinary literacy and engagement with materials) as a result of careful integration of oral communication with engineering skills like computer aided design and 3D-printing technology?

4. Outlining the redesign: stronger emphasis on physics; improved alignment and integration

In the redesigned course, while the basic structure remained the same, multiple changes were made. The students were tasked with conceiving, designing, and 3D-printing a plastic toy; the toy was expected to clearly accentuate a specific physical/mathematical phenomenon. Concurrently—this simultaneous work stream was viewed as critical—the students were required to prepare an A0-poster and poster presentation with a strong emphasis on the physics and/or mathematics of the toy (two posters from the students’ final presentation can be seen in figure 1). During the second week of teaching, a communication teacher from the university’s Department of Communication and Learning in Science gave a lecture focusing on the poster as a central communication genre in the physics discipline. The objective of the lecture was to raise students’ awareness about how a poster is a vehicle for communicating knowledge in physics, the particular challenges involved in designing and presenting an academic

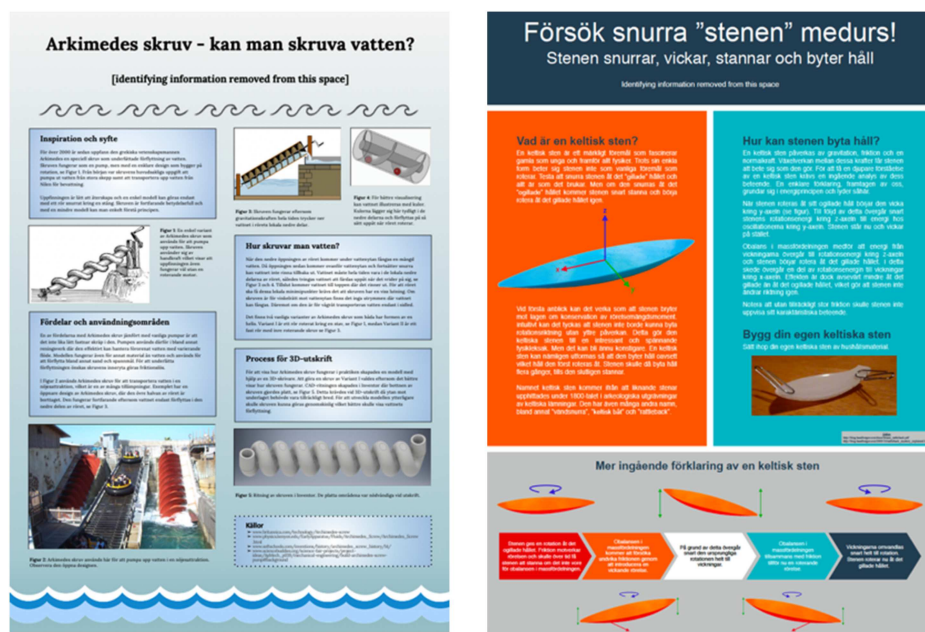


Figure 1. Two student posters presenting Archimedes' screw and a rattleback/celtic stone.

poster, and the disciplinary expectations regarding the presentation of physics/mathematics content.

The motive for choosing poster presentation as the format for the final assessment was deliberate. First, it was considered vitally important for maturing engineering physicists to develop disciplinary literacy and awareness concerning the multiplicity of genres relevant in the discipline, i.e. to attend 'to the wider network of situations in which they need to... speak... [this being one of the] hallmarks of membership in a discourse community' [17, p 8, 11]. Macintosh-Murray [18, p 352] concur, noting that 'in addition to acquiring [disciplinary] knowledge, students also must learn the language and means of communicating that knowledge, including the written, visual, and oral means that make up academic discourse'.

Another reason for selecting poster presentations is that physics students need to be prepared for engagement with a disciplinary community beyond the course-specific—often highly academically oriented—assessment task. Poster presentations appear particularly useful in this regard as they tap into students' transferable ability to contextualize scientific content and synthesize information from various sources [19]. Moreover, posters require students to 'narrow... down [scientific content], use... compact language, and maximize... the use of clear visuals' [18, p 356]. Arguably, these are all worthwhile skills to have in multiple discourse contexts in engineering physics (for a detailed account of what the expectations on oral communication in the engineering disciplines are, see [16]).

During the course, the students received feedback (largely framed as formative encouragement, cf. [20]) on their poster design and the physics and/or mathematics content in two poster workshops featuring two communication teachers and three physics teachers.

To facilitate the students' preparations, and in the interest of transparency regarding the summative assessment, detailed (rubric-style) evaluation criteria, informed by good principles

of engineering presentations [16], were introduced to grade the poster as well as the presentation; the criteria were available to the students throughout the course and they were developed with the intention to put equal emphasis on assessment of communication and disciplinary knowledge, thereby enhancing the sense of integration of physics and communication (the criteria are included as appendix A). The students were actively encouraged to revisit the criteria multiple times and to use them to self-assess and interpret their own development towards the learning objectives (cf. [19]).

The final assessment took place during a conference-like poster session which included 60 posters (in 2018), 58 posters (in 2019), 61 posters (2020) respectively; project groups typically included two students. A team of ‘judges’ (comprising two physics teachers, a communication teacher, and two CAD-tutors/PhD-students) walked from poster to poster and listened to students giving a 3 min presentation of their poster and the 3D-printed toy itself. The judges typically asked follow-up questions with the intention to probe into students’ disciplinary knowledge and to understand communicative choices made. Fellow students, senior students on the program, and physics faculty walked around the room and created an inspiring buzz. Posters and presentations were graded (pass/fail) based on the evaluation rubrics. As an incentive to work hard in the course, a prize (a study trip to Deutsches Museum in Munich) was awarded for the best (fours) poster presentations in the class.

5. Method

The process leading up to and involving the transformation of the project module, particularly the systematic and reflective inquiry among the teachers involved, recalls action research, i.e. ‘teachers researching their own practice of teaching... in order to improve their students’ learning [whilst] seek[ing] an improved understanding of the educational situations in which they teach...’ [21, p 434].

A central component of education based action research involves the testing of ideas for improved teaching; standardly, this means introducing some change in the learning environment—in the present case the main changes were represented by a tweaked instructional approach based in the notion of situated communication pedagogy, and a new form of assessment afforded by the poster genre. It is important to bear in mind that action research of the kind adopted here is ‘interpretive rather than explanatory’ and ‘concerned with seeking understanding [and] meaning’ of the teaching and learning practices/conditions under investigation rather than proving that the intervention introduced applies in all cases; consequently, ecological validity is typically considered more important than external validity [ibid.]. Nevertheless, the impact (or lack thereof) on different forms of learning from the new learning strategy/activity must be demonstrated at some level: ‘[teachers] need to show that what they have learned is true in the particular case of their teaching in their classrooms’ (ibid., p 437).

Multiple methodologies/mixed methods are the mainstay of action research [22]. Whatever methods are adopted they should ‘open horizons of discussion, [and] create spaces for collective reflection in which new description and analyses of important situations may be developed as the basis for new actions’ [22, p 72]. In the present study, three different methods, mutually supportive and enabling triangulation of the data gathered served these general purposes of action research.

First, many of the teachers’ initial pedagogical reflections from this course were based on individual and unstructured yet reflective field notes (cf. ‘jottings’—cf. [23]) from observations concerning aspects of physics learning and developing communication skills. The design

of the course, with an emphasis on student action, enabled the teaching team to assume the role as occasional observers of the broader learning context, and the behaviors of students' and the other teachers in that context. The field notes prepared by the teachers, sometimes just notes from memory, formed the basis for pre- and post-class and end-of-course conversations between the teachers involved, occasionally also involving students; effectively, the teachers engaged in more or less structured reflections and conversations concerning the actions implemented as part of the redesign.

Second, during the final week of the course, and following the poster presentation examination, we surveyed the students through a quick online (Google forms) questionnaire. A majority of the questions related directly to the students' learning in the course as impacted (or not) by the intervention. For half of the questions, we asked the students to indicate on a Likert type scale ranging from 1–5 the extent to which they agreed with a statement ('1' indicating strong disagreement and '5' indicating strong agreement). The remaining items were open questions enabling us to collect some qualitative comments from the students. One hundred and sixty-three students out of a total of 357 (over three course cycles) responded to the survey ($\approx 46\%$). At 46%, while slightly disappointing, the response rate should be considered acceptable for this type of online survey using convenience sampling and, importantly, we do not believe that the rate impacts negatively on the reliability of the survey or produce a biased response (cf. [24]).

Finally, in order to probe deeper into some of the themes emerging from the student survey and to clarify and validate some of the observations and reflections from the teachers, a student focus group was arranged. The focus group consisted of seven students who met online in a virtual meeting room for an hour-long discussion. The selection of the participants was randomized based on the entire cohort. One communication teacher and two physics teachers jointly assumed the role of moderators. The question/discussion prompts adopted recalled those used in the survey, though the wording was changed to fit the focus group discussion format.

6. Results and discussion

Through the survey, the focus group, and by way of informal comments during the course and after the examination, students confirmed that the module taught them to use basic level CAD, how to use 3D-printing technology, and how to design and present a poster. While unsurprising, all of this is consistent with our expectations and the formal learning objectives of the course. We were pleased to note that more of our students agreed than disagreed that the design project had been important for their development as engineering physicists (45% of the cohort indicated clear agreement, i.e. answered a '4' or '5' on the survey question, vs 16% disagreeing, i.e. answered a '1' or '2' on the survey question (mode value = 3), see figure 2, and that the design project had increased their interest in physics (39% clear agreement vs 24% disagreeing (mode value = 4), see figure 3. One student in the focus group expressed the following view:

I particularly enjoyed the fact that you did something from beginning to end, you started with an idea and you were able to realize it, to actually make the toy work; in a way, you owned the entire project.

This opinion was confirmed by a number of other students we spoke to following the final poster presentation; they remarked how the design project as a whole had provided a sense of 'doing physics as an engineer', and how the learning activities 'seemed authentic' and had 'empowered' them for the future. One student responded to an open question

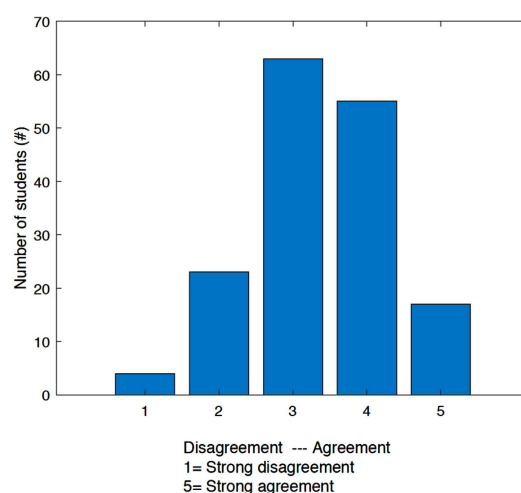


Figure 2. ‘The design project was important for my development as an engineering physicist’.

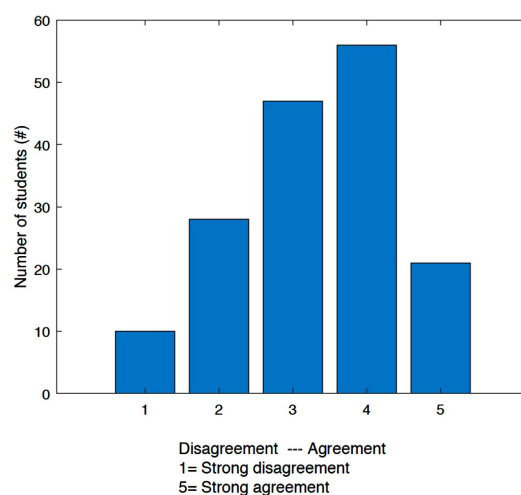


Figure 3. ‘The design project increased my interest in physics’.

in the survey by noting how the design project had provided ‘*insights*’ into ‘*what working as a physicist*’ means. The productive engagement with tasks, techniques, technology and a genre typical of engineering physics meant that the students engaged in meaningful and authentic activities and ‘engaging learners will help facilitate and stimulate effective and purposeful learning by students’ [25, p 92]. Carter, Ferzli and Wiebe [26, p 281] label such learning activities ‘socialization into the discipline’ and note how the ‘meaning and purpose [is] derived from the connection between the [task] and the scientific community’ [26, p 296]. The students’ remarks, survey responses and also our observations were clearly reminiscent

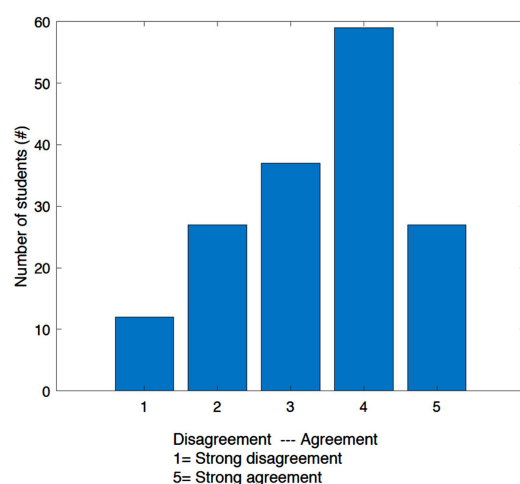


Figure 4. ‘My understanding of the physics and/or mathematics involved was positively affected by my working with poster presentations.’

of an emergent ‘discursive identity’, i.e. a sense and recognition of belonging to a discourse community.

Surprisingly, though, in the students’ opinion there did not seem to be a connection between their positive experiences in this regard and ‘learning physics’ per se; a majority of the students surveyed and interviewed claimed that they had not learned any new physics as a result of the project. One student in the focus group expressed it thus:

No, I did not learn any new physics—I knew the physical concepts underlying our toy already ... The physics concepts highlighted by many of the toys represent rather simple physics.

This suggests a rather narrow perception of what constitutes physics (especially perhaps in the engineering tradition) where mastering certain technology and experimental techniques, and acquiring fundamental skills like communication is integral to the subject itself. This kind of knowledge, apparently, is not considered central in the same way that concepts covered in a lecture or on an exam would; only the latter count as ‘teachable’ and ‘learnable’ new physics.

It was encouraging, however, to learn that many more of our students agreed than disagreed that their understanding of the physics and/or mathematics involved had been positively affected by their working with poster presentations (55% indicating clear agreement vs 23% disagreeing, mode value = 4), see figure 4, thus confirming earlier research attesting that ‘students who engage in oral communication practices eventually have a better grasp on the content of the course’ [7, p 148].

Our observations during the course provided further confirmation in this regard, and the drop-in poster workshops are a case in point. In the workshops, discussions and questions about fonts, layout and other questions relating to ‘surface’ phenomena were backgrounded (for this last point, see [18]). There was some talk about macro structuring and the amount of content/information that could feasibly fit on the poster (and what content might be eliminated). However, the students primarily seemed to be discussing aspects of physics, the presentation of physics, and things like whether and how they might integrate equations and

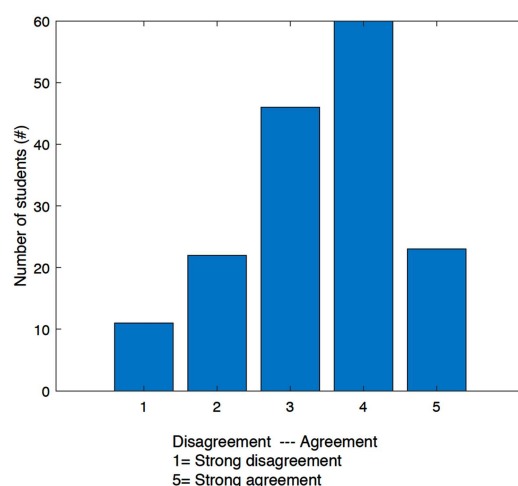


Figure 5. ‘My physics presentation skills were positively affected by their my with poster presentations’.

formulae in the poster. The workshops thus effectively amounted to disciplinary spaces for talking about physics—where ‘complex disciplinary, epistemological, ideological knowledge ... is negotiated’ [7, p 148]. A case in point was this: during one of the poster workshops, a conversation between a physics teacher and two students took place. The students wanted to clarify their understanding of the direction of force for a moving object, using a draft version of a figure on the poster as their starting point. This figure, particularly the mistakes the students had made in preparing the figure, prompted a 17 min discussion about physics, and the physics teacher and the students took turns at the black board. Arguably, this constitutes a prime example of communicating-to-learn physics (at multiple levels and using speech, writing and visualization).

Students who attended the workshops (only a minority did) queried the teaching team about various aspect of their project. In some cases, there was something about the physics or the mathematics that they did not understand and wanted to have explained. In other cases, students seemed more interested in receiving our confirmation that their understanding of the physics and/or mathematics was correct. We noted how the students benefitted from this additional opportunity to talk informally about physics and/or mathematics within and across project groups and with the teachers—this was evidenced not least by students’ spontaneous remarks during the workshops, remarks which clearly indicated new levels of understanding and critical reflection on their own as well as others’ work.

Previous research has suggested that encouraging students to develop their individual disciplinary voice, effectively to speak about physics as physicists do, can result in positive learning outcomes (cf. [12, 27]). Also, ‘designing in’ opportunities for student talk in a course the way we did with the posters, the CAD training seminars and the hands-on engagement with 3D printing is positively associated with the development of a discursive identity, as noted by Allie *et al* [1, p 361], emphasis added:

Sitting passively in a lecture hall gives limited opportunities for developing your identity, and that is why we need to include in our [engineering] programmes

many more opportunities to *discuss* technical problems with peers, to *present* one's findings, and sometimes even just to *engage* socially with other engineering students.

In addition to empowering the students to develop a discursive identity, designing the posters and preparing and delivering the poster presentation also seemed to help the students structure their arguments and critically reflect on the physics/mathematics of their project. During the poster evaluation, it was very clear from the students' presentations and their posters who understood the physics/mathematics of the project and who did not, and the judges' probing questions provided corroborating evidence, especially when a question was posed in order to test the strength of the students' physical/mathematical argument. While all students took the task seriously and produced a well-designed toy as well as a poster, the spectrum of understanding the physics underlying the toy differed. Overall, our observations confirm those highlighted by [8]: the poster component of the course enabled students to 'critically evaluate the quality and structure of their arguments, [and] speaking about [disciplinary content] is itself an exercise in critical thinking and learning' [8, p 11, 18].

The teaching team were inspired to learn that many more of our students agreed than disagreed that their physics presentation skills had been positively affected by their working with poster presentations (52% indicating clear agreement and 21% disagreeing, mode value = 4), see figure 5, confirming research findings of integrated oral communication settings in other disciplines (e.g. [7, 8]).

It was clear from the way students talked about the poster presentations that, for virtually all of them, this was a new oral genre, involving a different set of audience expectations, and a decidedly different atmosphere for the presentation (cf. [18]). Several of the focus group comments provided evidence in this regard:

The poster presentation was fun—but at the same time very challenging. I have never had to condense a presentation like that before—a poster has to be very information dense.

The other format [a traditional monologic academic presentation], I have done that so many times, in different ways. This format was really different—now I had to think a lot more carefully, about different recipients and the like... I was more selective of the information I put in, I think.

A communication teacher noted how the poster format seemed to have a deliberating effect on the students—very few students used speaking notes, and virtually none of the presentations seemed scripted (a trait that typically plagues other forms of first year academic oral presentations).

One student made the comment that it was '*interesting to get a sense of what the engineering physics standards for presentations are like*'. While perhaps primarily intended as a comment about the presentation per se, the student's remark actually addresses a point of epistemology relating to oral communication: oral genres like the poster presentation 'are expressive of what a discipline counts as valid knowledge' [1, p 149], and we were pleased to see this student, perhaps inadvertently, make this connection. We raised this topic in the focus group, generating this interesting response from one of the participants:

I suppose it is really quite valuable to be able to handle a poster—we have seen them [posters] all over the physics building, outside offices and the like, and it is clear this is an established way to communicate as a physicist.

Whether or not representative of the student group more broadly, another student's comment after presenting their poster was equally encouraging for us:

*I will feel so much more confident giving oral presentations going forward now ...
This poster presentation was fun ... more like telling a story than a dry formal presentation.*

The student's reference to 'story' is significant as it suggests that the student has realized that features of 'storytelling' can be superior to an exposition format in a poster presentation (interestingly, this is not something that was emphasized during the course). This rhetorical strategy may resonate with an audience in the transient oral context that is the poster session because 'stories improve comprehension and recollection by leveraging people's semantic memory process' [28, p 223]. Student experiences like those reflected by this comment lead us to believe, therefore, that the opportunity to work with poster presentations could help fostering a more nuanced, situated, contextually developed and advanced conception of oral communication among the students.

7. Concluding remarks

Action research such as this does not lend itself to generalizable statements about learning applicable across educational settings. However, the work we did in this course enabled us usefully to explore and interpret teaching and learning practices in our local learning environment and, to this end, our experiences are encouraging. The observed outcomes of integrating oral communication with engineering physics reported in this paper largely confirm previous research from other STEM disciplines: structured oral engagement with disciplinary content appear to confer multiple learning benefits and promote the development of disciplinary (physics) literacy. It is our hope that sharing these experiences with the community of physics educators will encourage others to reflect, and perhaps try similar integrated educational designs.

Note on research ethics

The research reported here was carried out in accordance with the principles outlined in the *European Journal of Physics* ethical policy. No ethics approval was required from the university for this action research. Approval was obtained from the Program Manager for the program in engineering physics. All students in the course received information about the research being conducted and how the data were going to be used. All students responding to the questionnaire and/or participating in the interview gave their informed consent. No data collected as part of this study can be attributed to an identifiable individual (the survey was anonymous, and no names were recorded for students participating in the interviews).

Appendix A

The following rubrics were used to assess the poster (design) and the poster presentation respectively.

Poster design	Satisfactory (P)	Unsatisfactory (F)
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Criteria

1. The **overall impression** of the poster contributes to the audience's interest in the toy
2. **Graphic and figures** enhance the messaging of the poster
3. The **information flow** of the poster makes navigation easy
4. **Key information** is centered or foregrounded through other means
5. **Font** and **font size** collectively give a credible impression
6. The text is **clear, logical** and **effective**, i.e. **coherent**
7. The text contains few or no language errors, i.e. it has been **proofread**
8. The content of the poster is **relevant** and **balanced** (i.e. there is neither too much nor too little information)
9. **Numbers** and other forms of **evidence** enhances the argumentation/message
10. The poster **clearly demonstrates and explains the physical phenomenon** and the connection to the toy
11. The poster is **results oriented**, i.e. focuses on the outcome of the design process and the **physics** (rather than the design process as such)
12. The message of the poster is evident even without the presenters' explanations, i.e. the poster **can be read independently**
13. The poster **authors** are easily **identified**

Comments:

Presentation of poster	Satisfactory (P)	Unsatisfactory (F)
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Criteria

1. The presentation is **interesting** and **engaging** (without exaggerations)
2. The presentation is **adapted** to the **intended audience**
3. The presentation gives a **credible impression**; the presenters are **in control of the topic** (which includes the physics)
4. The presenters are well **prepared to respond to questions** from the audience
5. The presentation has a **clear structure**
6. The **poster** offers **visual support to the presentation** and is well **integrated** with the delivery
7. **Vocabulary**, including **physics terminology**, used during the presentation **matches the poster expression**
8. **Vocal resources** are used well (tempo, volume etc)
9. The presenters have **timed** their presentation well

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